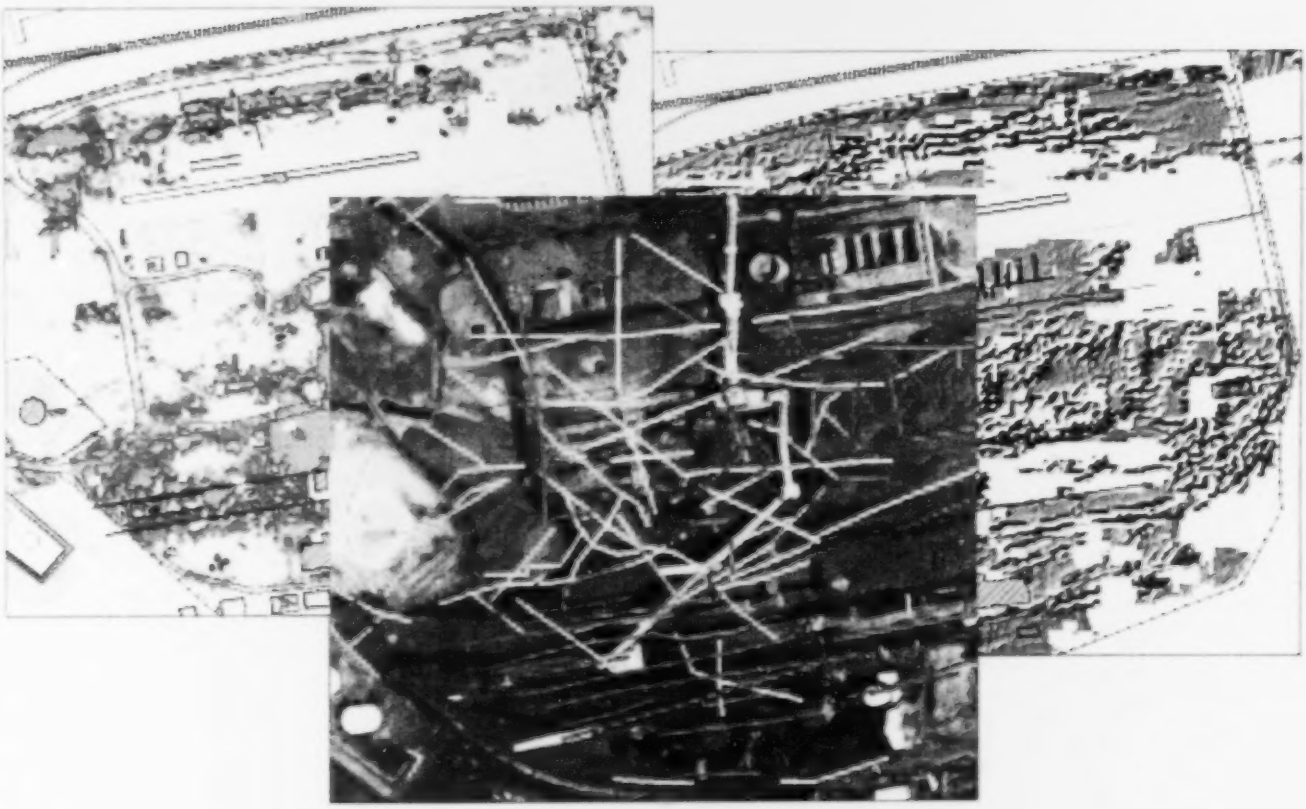
Geophysical Survey of the Coke Ovens Site and its Surroundings
Sydney, Nova Scotia
Winter 1999



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GEOPHYSICAL SURVEY OF THE COKE OVENS SITE AND ITS SURROUNDINGS, SYDNEY, NOVA SCOTIA. WINTER 1999

EXECUTIVE SUMMARY

Geophysical surveys were carried out on the area known as the Coke Ovens Site (COS) and its surroundings in Sydney, Nova Scotia, during 5 weeks in January and February, 1999. The surveys were undertaken in preparation for the Phase II investigation of this site. Their objectives were to identify subsurface infrastructure and anomalous soil and groundwater conditions that would require consideration in planned Phase II investigations. A 5 day "test phase", in which various geophysical technologies were tested and an approach defined, preceded the full survey. The interdisciplinary project team included geophysicists and hydrogeologists, as well as the manager of the site during its' final years of operation. This team has geophysically identified hundreds of anomalous subsurface features. Many of these have been linked to both known and previously unrecognized infrastructure, and to potential sources of ground contamination.

The survey consisted of:

(1) Establishing a site co-ordinate system based on 1 hectare grid nodes which have been located with a global positioning system (GPS).
(2) Approximately 33 hectares of terrain conductivity profiling, using the Geonics EM-31 on orthogonal grids of lines spaced 4 metres apart, with readings typically every metre. This survey located subsurface conductivity anomalies and metallic objects in the upper 3 to 5 metres, and was carried out primarily on the COS proper.
(3) Approximately 25 hectares of terrain conductivity profiling using the Geonics EM-34 on lines spaced by 40 metres in areas to the east (the "Marsh Dump"), south ("Mullins Bank"), and southwest ("boundary") of the main COS site. This survey was used to locate any areas of widespread inorganic groundwater contamination in the overburden and uppermost bedrock.
(4) Geophysical logs (conductivity, gamma) of six existing boreholes on the site. These data were used to determine the vertical variations in clay content and electrical conductivity beneath the sites, as well as identify anomalous conditions.
(5) Data from short test surveys of ground penetrating radar, seismic refraction and VLF resistivity techniques made as part of the earlier 5 day test phase of the project.

The main results are as follows;

(1) *The EM-31 scan of the site reveals a large number of elongated anomalies which are classified as linears (e.g. pipes, tunnels, cables, ditches), zones (high conductivity values typically indicating ground contamination), and metals (highly conductive localized metallic objects other than those which form the linears). Over 500 linear and 200 metal anomalies are identified. Spatial resolution of the targets of these anomalies is estimated to be +/- 1m.*

The site has been divided into 4 zone levels, for measured conductivities in the ranges (mS/m) 50-100, 100-200, 200-300 and >300.The zone anomaly map is dominated by an extremely high conductivity, blocky anomaly pattern that we believe to be the result of highly metallic slag historically used as fill for roads and building construction. Because modern slags appear to be relatively low in their metal content, we may be looking at the patterns of fill originating from the turn of the century to the 1950's. Surrounding and interspersed between these extreme highs are zones of lower but still highly anomalous conductivity, probably representing high total dissolved solids (TDS) levels in the groundwater and perhaps less concentrated deposits of slag.

The geophysical descriptions of each linear and metal anomaly, and some comments as to possible sources where appropriate, have been entered into a data base from which the most relevant data have been extracted in Appendix C. Figures 4.1-4.4 display the geophysical data in various formats while Figures 5.1 and 5.2 summarize our interpretations of these maps. The contoured data and the interpretative diagrams are also provided as .DWG files.

It must be emphasized that these data identify anomalous ground conductivity. There will be some cases where difficulties arise in correlating the more subtle variations in ground conductivity substructure to readily identifiable objects or ground contamination. These maps, however, provide a detailed guide to possible subsurface conditions as a basis for further Phase II investigations.

(2) *The EM-34 data are contoured and presented in Figures 4.5 to 4.8. This instrument yields a (weighted) average of ground conductivity to depths of 7 to 30 metres depending on the configuration. The figures show that the averaged ground conductivity levels to these depths in the Mullins Bank and Marsh Dump areas are low compared to the upper few metres of the COS itself. The Marsh Dump area has significant amounts of metal (including buried rail lines) but displays no signs of pervasive highly conductive contamination connected to the Municipal Landfill. The Mullins Bank area has minor variations in its (overall low) conductivity that may reflect minor contamination from the COS. In the boundary area southwest of the Benzol Tanks, EM-34 readings are distorted by nearby metal but overall appear to show a higher-than-normal ground conductivity. This area should be further investigated to see if it is receiving a plume of contaminated groundwater from the COS site proper.*

(3) *The geophysical logs are summarized in Figures 4.9a-f. A feature of the two logs from the COS site proper is that they exhibit relatively low but irregular electrical conductivities throughout most of their length. High conductivity values only exist as thin layers within the upper 3 metres of the record. There is no evidence at these holes for pervasive inorganic groundwater contamination throughout the section. Along the boundary of the Municipal Landfill, the geophysical logs suggest (through elevated electrical conductivities) that groundwater contamination is present but*

concentrated in narrow, probably fractured, zones. These logs show the value of continuous geophysical measurement with depth, as a compliment to one or two point screen measurements of water chemistry, in evaluating the nature of contaminant flow in the subsurface.

The geophysical survey has accomplished its objectives. The data are provided in the form of detailed maps and catalogues of subsurface anomalies that should be addressed in future investigations. Because all these are tied into the local GPS coordinates, they provide a square metre by square metre template for the drilling, sampling or excavation programs to follow.

Table of Contents

1 INTRODUCTION **1**
1.1 The Coke Ovens Site 1
1.2 Site History 1
1.3 Survey Objectives 2
1.4 Geological and geophysical properties of the site 3
1.5 Geophysical responses to physical properties 4

2 TEST PHASE **6**

3 FIELD WORK **7**

4 RESULTS **9**
4.1 The EM-31 data and an overview of their interpretation 9
4.1.1 Lateral and vertical resolution. 9
4.1.2 The Data. 10
4.2 The EM-34 data and overview of their interpretation 11
4.3 The geophysical well logs 13
4.3.1 Geophysical logs on the Municipal Landfill boundary 13
4.3.2 Geophysical logs within the COS 15

5 INTERPRETATION **16**
5.1 EM-31 anomalies: how they are described 16
Category L, Linear Features 16
5.1.2 Category R, Rectilinears. 17
5.1.3 Category M, Metal 17
Categories Z (Zones) 18
5.2 Details of the EM-31 anomalies 19
5.2.1 Linears 19
5.2.2 Metals 20
5.2.3 Zones 20
5.3 EM-34 interpretation 22
5.3.1 Modeling 22
5.3.2 Implications for ground contamination 23
5.4 Geophysical well logs 23

6 USING THIS INFORMATION **25**
6.1 The overall view. 25
6.2 Investigating small areas. 25
6.3 Extracting more information from these geophysical data. 25

7 CONCLUSIONS AND RECOMMENDATIONS **30**
7.1 The Coke Ovens Site: a summary 30
7.2 Refining the detailed interpretation of linear and metallic anomalies 30
7.3 Groundtruthing the COS geophysics by selected sampling 31
7.4 Mapping bedrock. 31
7.5 Geophysical well logging. 32

8 REFERENCES 33

9 LIMITATIONS OF REPORT 34

Appendix A – Equipment & Theory

Appendix B – Test Phase Report

Appendix C – Tabulated Anomalies

Appendix D – Survey Node Coordinates

Appendix E – Glossary

LIST OF FIGURES.

Figure 3.1 Location of geophysical measurements , Coke Ovens Site.

EM31 Data

Figure 4.1 Contoured EM-31 conductivity measurements.
- a. Apparent conductivity data (NS)
- b. Apparent conductivity data (EW)

Figure 4.2 Contoured EM-31 in-phase measurements.
- a. In-phase data (NS)
- b. In-phase data (EW)

Figure 4.3. Shaded Apparent Conductivity (EW)

Figure 4.4 Shaded Inphase Data (NS)

EM34 Data

Figure 4.5. Apparent Conductivity Data 10m Separation – Horizontal Dipoles

Figure 4.6. Apparent Conductivity Data 20m Separation – Horizontal Dipoles

Figure 4.7. Apparent Conductivity Data 20m Separation – Vertical Dipoles

Figure 4.8. Apparent Conductivity Data Processed 20m Separation- Horizontal Dipoles

Borehole Data

Figure 4.9. Geophysical well logs
- a. JAG-GW2D
- b. JAG-GW3D
- c. JAG-GW4D
- d. JAG-GW5D
- e. BH-11
- f. BH-13

Figure 5.1 Interpretation – Linear & Metal Anomalies

Figure 5.2 Zonal Apparent Conductivity Anomalies.

Figure 5.3. Schematic Plume Cross-Section

Figure 6.1. Hectare (E6) - Shaded Apparent Conductivity Data (EW)

Figure 6.2. Hectare (E6) - Interpretation – Linear & Metal Anomalies

Figure 6.1. Hectare (E6) - Zonal Apparent Conductivity Anomalies

Table 6.1. Hectare (E6) Database of anomalies,

1 INTRODUCTION

1.1 The Coke Ovens Site

The Coke Ovens Site (COS) is located within the Muggah Creek watershed in Sydney, Nova Scotia. The COS is one of several areas within this watershed that have seen extensive industrial usage in the past century. Other areas include the SYSCO steel plant, the former CN railyard, an Imperial Oil tank farm and distribution centre, coal storage areas, the Marsh Dump where slag, brick, granular coal and coke debris are as much as 20 metres thick, and the current Municipal Landfill. Together these areas within the watershed have been the subject of a Phase I Site Assessment by CBCL Ltd and Conestoga Rovers and Associates (CBCL/CRA, 1998). As reported in that study, one legacy of the coking operations at COS is the estimated 550,000m^3 of contaminated sediments deposited by Coke Ovens Brook in the "Sydney Tar Ponds" within the Muggah Creek Estuary where it enters the Sydney harbor. This present study, concerns the ground contamination and derelict infrastructure that still remains beneath the COS.

1.2 Site History

The following description draws on the comprehensive Phase I document, and summarizes only those features and activities at the site that have relevance to the geophysical survey and its interpretation. The processing used to transform coal to the coke needed to fire the blast furnaces of the steel mill began in 1899. Coal stockpiled on the site was crushed and blended, then fed to the battery ovens to be fired (at 1200°C) into coke and finally quenched with water . Each kilogram of coal produced 750 grams of coke, with the remaining 250 grams released in the ovens as gas. The gas was then processed for by-products. Coal tar and water were removed first, and the water and remaining gases further processed for ammonium sulfsulfate, napthalene and (from the remaining light oil) benzene, toluene and xylene. The production of ammonium sulfate required sulfuric acid, made from sulfur on the site. These various products were moved around the site (pipelines, conveyor belts, off-road vehicles, etc.), stored (piles, tanks, etc) and – inevitably – spilled onto or into the ground.

The COS was closed in 1988. Over its 89 years of operation generations of extensive

surface and subsurface infrastructure grew on the site. With time these pipelines, tanks, railways, buildings, etc. would be expanded, abandoned, and replaced. Records of these alterations were not always made, or perhaps not always kept. The result today is a 33 hectare site, stripped of most of its superstructure, but underlain by an extensive and decaying infrastructure. It has been estimated [1] that the COS area contains as much as 90 km of associated underground piping, ranging in diameter from 25mm to 900mm at depths ranging from 0.5 to 6 metres. In addition there is ample evidence of extensive inorganic and organic contamination of the soil and groundwater

The Coke Ovens Site today is encircled by steel mesh fencing. The geophysical surveys took place mainly within this fenced area, but the RFP also requested information on ground conditions beneath an adjacent area to the east, more or less coincident with what is known as the Marsh Dump, and on the adjacent area to the south known as Mullins Bank. The Marsh Dump lies between the COS and the current Municipal Landfill and it is an area where (according to the Phase I report) slag, brick, granular coal and coke debris have been placed in deposits as much as 20 metres thick. The resulting ground contamination, and also potential contamination in or beneath these deposits caused by leaching from the Municipal Landfill are the immediate concerns. Mullins Bank, as far as can be determined, is natural ground on which coal was stored during the period from the 1930s to the 1980s. Today it has been returned to an apparently natural state, but the quality of the groundwater is unknown.

1.3 Survey Objectives

As an early step in the clean-up, this geophysical survey was commissioned to identify as much of this infrastructure and contamination as possible.

The objectives were stated in the RFP as follows.

- locate subsurface utilities, infrastructure and waste
- determine natural geologic and hydrogeologic conditions
- delineate trench boundaries
- determine sub-surface inorganic contaminant plumes emanating from Mullins Bank and the Municipal Landfill areas.

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[1] Eric Parsons Sr., former site manager, personal communication.

1.4 Geological and geophysical properties of the site

The geological and hydrogeological properties of the site have been well described in the Phase I report (CBCL/CRA, 1998, Ch. 2 and Figure 2-4) and will not be repeated in detail here. Very basically the natural geology consists of glacial till overburden (1 to 10m, typically 3m thick) overlying sedimentary bedrock. The till is described as silty sand to silty clay, with some gravel. Bedrock is primarily the Morien Sandstone, described as a fine to medium grained unit with thin lenses of shale/mudstone and coal, and can be highly fractured on its upper surface.

Overlying this natural geology is a layer of fill which is thought to be 2 m thick on average but may reach 5 m. The fill is described in the Phase I report as follows:

."... sand, gravel, concrete rubble, coke, cinders and steel plant slag; fill materials are extensively contaminated with coal tar and other by-product derivatives of the coking process" (CBCL/CRA, 1998, Table 2.2).

The water table is typically 1 to 3 metres beneath the surface (CBCL/CRA, 1998, Figure 2-3), near the base of the fill or within the till.

Particularly relevant to the geophysical work is the electrical conductivity of these materials. For the natural materials we have a number of geophysical well logs, two of which (BH-11 and BH-13, Figures 4.9e and 4.9f respectively) were performed on the site itself. They show average conductivity values for the till and the upper layers of bedrock as 20 and 5 mS/m respectively. The conductivity in the upper three metres in those two holes is very variable (indicative of metallic fill), with a base level of 10 mS/m and peaks exceeding 50 mS/m. As will be described later, we have found extremely high ground conductivity values (as much as 400 mS/m) with the EM-31 surveys which sample the upper 3 to 5 metres of the ground.

Of the fill materials identified above, the slag would seem to have the greatest potential for achieving these high conductivities. High levels of inorganic contamination (as might exist, for example, in the immediate vicinity of the sulfur piles) could perhaps produce these conductivity levels in some locations but are unlikely to be the cause in general. However, there was seldom correlation between elevated terrain conductivity and visible slag on surface. Further, the samples of slag we found on the surface did not look to be electrically conductive; they appeared as chunks of slightly fused calcium carbonate (from the limestone used in the steel making process). Clearly the origins of these extreme conductivities are one objective of this survey and its follow up.

1.5 Geophysical responses to physical properties

The major controlling factors of the bulk apparent conductivity of the subsurface include porewater conductivity, the porosity of the formation, and its clay (or other conducting mineral (e.g. graphite, sulfide)) content. "Leachate" from most landfills will tend to have a significantly higher electrical conductivity when compared to 'clean and natural' groundwater. Typically the leachate will contain chloride ions and other dissolved species, which will increase the conductivity of the groundwater. Consequently, as leachate moves through the ground it tends to increase the naturally occurring bulk apparent conductivity of the subsurface. This conductivity contrast between material saturated with natural groundwater and that portion of the ground containing conductive leachate ('plume') allows the contaminant to be mapped by measuring the changing electrical conductivity (or its inverse the electrical resistivity) of the subsurface.

It should be noted that the ability to detect and recognize geophysical anomalies that are produced by conductive groundwater contaminants is highly site specific and is dependent on a number of factors. These factors include the concentration of the contaminant, it's depth and thickness, the host geology, and local sources of electromagnetic noise.

If the subsurface is sufficiently conductive that instrument readings are clearly above the normal ground conductivity, designating the area as geophysically anomalous is relatively uncomplicated. However, in many cases the identification of subtle conductivity variations as anomalous can be difficult and depends heavily on visual pattern recognition. The pattern would normally include a connection to the source and a trend of decreasing conductivity values extending away from the source(s). The limits of the "anomalous" zone cannot be identified without first defining what is <u>not</u> anomalous (i.e. "background".)

Background apparent conductivity values can vary considerably, depending on – for example - geologic variations and changes in the water table depth. If water conductivity were uniform throughout the site, areas where the water table is shallow (e.g. near surface water, or moist low lying ground, such as was noted throughout portions of the survey area) will tend to have higher conductivity readings when compared to areas that are topographically elevated.

Defining "background" conditions would be complicated, and the pattern of leachate migration from the source more difficult to define, if those porewaters which have not

been influenced by the presence of the contaminant also had a spatially variable conductivity.

It is unlikely that the limits of anomalous zones, as inferred from the geophysical data, will correlate exactly with 'real' limits of contaminant migration based on accepted groundwater quality standards. The geophysical anomalies will however be relatively indicative of porewater/soil conductivities and the direction of possibly existing conductive leachate migration..

Many forms of groundwater contamination leachate are not electrically conductive and will not be mapped by geophysical techniques. Each of these contaminants will have its own plume of concentration depending on mobility, adsorption and a variety of other factors. Fortunately, the "conductivity plume" is typically one of the most mobile of these plumes and therefore provides a conservative indication of contaminant migration.

2 TEST PHASE

A test phase preceded the main phase of the project. This test phase was used to establish the best geophysical methodologies for achieving the objectives of the Phase II project as a whole. The complete test phase report is included as Appendix B. A short summary follows.

On the basis of the test phase, Hyd-Eng Geophysics recommended an EM-31 scan of that area of the COS and of the small outliers of infrastructure shown on the site map just outside the northeast corner of the fenced area(roughly rectangular area with corner hectares I9 and J11, denoted henceforth as I9-J13). We advised using 2 orthogonal grids – one with survey lines oriented north-south and one east-west - and 4 m survey line spacings, as were successfully employed in the test phase. The EM-31 was to be run in the normal vertical mode, and oriented transverse to the survey line (see diagram below). The targets of this scan were described as shallow infrastructure, geological variations and ground contamination.

We also recommended an EM-34 scan of the Mullins Bank area (hectares B5:C5 through D10:E10), and the area (hereafter called the Marsh Dump) defined by the landfill to the east and (by projection) south, Frederick Street to the north, and the COS fence to the west(hectares F10-J13). We recommended using 20 and 10 m horizontal and vertical modes on 20 metre station intervals and 40 m line intervals. The targets of this survey were deep seated (5-30m) inorganic groundwater contamination, geological variation and large buried objects.

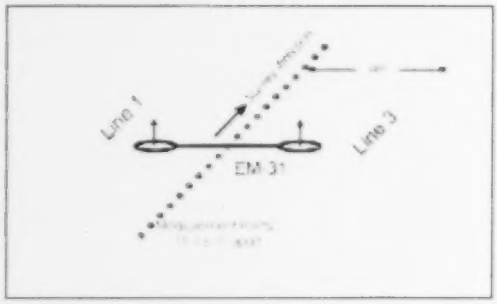
The report also recommended vertical detailing of selected anomalies identified on the EM scans, subject to the remaining available budget, to JAG priorities, and to the local geological and infrastructure environment.

3 FIELD WORK

The field work followed the recommendations of the Test Phase report with only minor deviations. The weather from January 8th, when the test phase began, to February 26th when the survey was completed, was generally mild for mid-winter. Remarkably there were few lost work days. On the other hand the short winter days limited the field time and periodic ice rain events impeded production and extended the work beyond the period anticipated in the proposal which assumed the project would start in early fall.

A geophysical survey grid was established over the COS site to allow the interpreted features to be relocated at a future data. The area was divided into hectares, identified (spreadsheet-like) by a letter and number. The hectare corners were laid out using a Geographical Positioning System (GPS) and marked with steel pins and flagging. The survey lines were marked with spray paint.

GPS positions were acquired with a a Trimble Pathfinder ProXR Receiver and TDC-2 Data Collector system, capable of a horizontal accuracy of 0.5 m. The coordinates used are referenced to the local (Nova Scotia) UTM grid Zone 4.



The field crew of four men used two Geonics EM-31s to cover the fine grid (see Figure 3.1) . The EM-31 data were collected along the lines at known intervals ranging between 0.75 and 1.6 m, depending on the instrument and the pace of the observer. Data were collected in all safely accessible areas. Data were not collected within structures, through excavation pits, over manways, through water or in other areas deemed as unsafe by site authorities or the field operator. In some cases the conditions at the time of surveying, i.e. snow, ice or water cover, dictated the classification of an area as unsafe. In areas where it was difficult to walk straight lines, the GPS was used concurrently to provide position information.

A Geonics EM-34 was used for the deep scan of the Mullins Bank and Marsh Dump areas. The EM-34 data were collected at approximately 20 metre station spacings along lines 40 metres apart. The location of each station was determined directly with the GPS (see Figure 3.1).

Geophysical well logs were obtained with the Geonics EM-39. The positions of the boreholes were measured with the GPS (see Figure 3.1).

The Coke Ovens and Mullins Bank sites have very minimal topography. No elevation corrections for these data were required. Local mounds of earth or debris were noted and their effects on readings accounted for qualitatively as deemed necessary. Most of the Marsh Dump area lies at a higher elevation than the other two sites and it also has more topographic variation. This variation does not, however, interfere with our interpretation of the EM-34 data in this region. The instruments used in the test phase and the main survey are described in Appendix A.

4 RESULTS

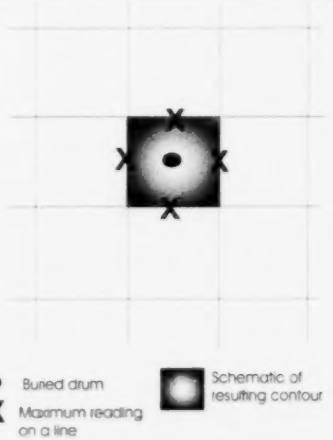
This section presents the data and describes their implications. A more detailed interpretation, where required, is given in Section 5.

4.1 The EM-31 data and an overview of their interpretation

4.1.1 Lateral and vertical resolution.

The vertical resolution of a terrain conductivity anomaly is basically described by saying that the target lies within the depth of penetration of the instrument. Some refinement of that statement is possible in specific cases based on the strength and sharpness of the anomaly, and on common sense (e.g. maximum likely depths of burial). The lateral resolution of a terrain conductivity meter is limited by the coil separation, by the line spacing, and by the station spacing along the line. In the configuration used here for the EM-31 we note the following.

a. A standard steel drum buried at 1 m yields an EM-31 anomaly on a close-spaced (1 m or less) grid that is approximately 4 metres wide, reflecting the separation of the coils. Thus the instrument smears even a narrow anomaly over this distance. However, the peak of the anomaly (in this case a negative) is directly over the target so lateral resolution is effectively constrained only by the station spacing along the line passing directly over the target. In our surveys that would be either .75 or 1.5 metres depending on the station spacing, assuming the line ran right over the target.



Detecting a drum on lines 4 metres apart: worst case scenario.

b. A worst-case scenario for our surveys would be a drum that lay between lines on both grids (N-S, E-W), depicted schematically in the diagram. In this case the drum would be detected (probably weakly) on each of the four adjacent lines, with the maximum occurring when the instrument is in line with the target (as shown by the

Xs). These four maxima are identified with a resolution equal to the station spacing; the contouring (depicted by the zonal shading) would interpolate the anomaly between these four points, and should place the peak within also within one station spacing (.75 to 1.5 m) of the epicentre of the target. (Note, however, that since the anomaly of the drum is dipolar, with a central negative flanked by weak positive highs, the contouring may well get the polarity wrong.

c. On the basis of this worst case scenario it is fair to say that the contoured anomalies can locate discrete metal targets with a horizontal resolution better than +/- 1.5 metre and usually better than 1 metre. Linear targets are likely to be resolved within less than +/- 1 metre.

4.1.2 The Data.

The EM-31 data sets for the site are presented in Figures 4.1 to 4.4; Figure 3.1 shows the location of the measurements. The measurements have been interpolated onto a 0.25 metre grid for the purposes of contouring. Figure 4.1 displays the conductivity and Figure 4.2 the in-phase measurements. Figures 4.1 and 4.2 each have two parts; "a" shows the data gathered in the north-south direction, while part "b" shows the data gathered in the EW direction. The conductivity and in-phase data are also displayed in shaded relief format (Figures 4.3 and 4.4 respectively). Shaded relief diagrams are produced by digitally treating the data as a surface. A "sun" is shone on the surface from a given direction and elevation to create shadows from the contoured data. This technique is useful in some cases to identify subtle trends and anomalies that may be difficult to distinguish in the colour presentation

We first describe these maps in general terms which should provide the reader with a broad understanding of their content, then move to a detailed interpretation in Section 5. In a broad sense the four maps in Figures 4.1 and 4.2 are basically similar. They are all "busy", but the overall impression is of anomalous (either red or dark blue) zones striking roughly 80°/260° through a more normal (green) background. Examination of the conductivity scale shows that the dark green represents roughly 15-25 mS/m, a reasonable value for the fill in this area according to the geophysical logs at BH-11 and BH-13 (section 4.3.2), but high in comparison to values observed in the underlying overburden and rock materials. The yellow and orange zones represent conductivity values ranging from 25 to 100 mS/m. Although these zones are interpreted as

anomalously conductive for this site, these values span the range commonly observed as the clay portion of a natural overburden material increases. The onset of the colour red represents ground conductivity values of about 100 mS/m. These are anomalously high conductivity levels, reached in natural sediments only in materials such as marine clays or sea water saturated sediments. The extreme reds with violet and purple represent conductivities of 200 mS/m and greater. Clearly very high levels of ground conductivity exist in the shallow subsurface beneath these red zones, probably the result of highly conductive fill and/or groundwater contamination.

A closer examination of the four maps shows that the limits of these highly conductivity zones are unnaturally rectilinear or "blocky". That is, the red zones tend to be truncated by sharp, straight boundaries. This is particularly evident on the in-phase maps; the in-phase component of the EM-31's response is less linear in its response to ground conductivity than is the quadrature ("conductivity") response and goes from low to high reading over a relatively short ground conductivity range. The blockiness on these maps is not typical of the pattern of groundwater contaminant plumes typically found, for example, around landfills or salt piles. The distinct boundaries probably reflect a pattern either in the original emplacement and/or constraints on the migration of groundwater contamination within these materials

A closer look still shows that the broad patterns described above are overprinted by a wide variety of smaller scale disturbances. The large majority of these are so-called "linear" anomalies that are characteristically long and narrow and which include the blocky zonal edges here termed "rectilinears". Others are localized negative anomalies characteristic of isolated bits of metal. Finally, the extensive high conductivity trends described earlier can be subdivided into a number of smaller zones that probably represent different conditions within the overall ground contamination pattern.

A Microsoft Access database has been used to collate the linear, metal and zonal anomalies identified based on their location, azimuth, the polarity and strength of the anomaly in each of the four component maps, overall strength and confidence levels, and comments on their nature and origin.

4.2 The EM-34 data and overview of their interpretation

The EM-34 data are shown in Figures 4.5 to 4.8. Figure 4.5 displays the 10m separation horizontal dipole mode data, while Figures 4.6 and 4.7 give the 20 m horizontal and

vertical dipole modes respectively. Figure 4.8 shows a combined form of the 10H and 20H data (2*20H-10H) that minimizes the influence of near surface material and accentuates the conductivity values at depth.

The coil spacing and the dipole orientation govern the penetration of this instrument. The 20m separation penetrates twice as far as the 10 metre (roughly 15 metres versus 7.5 metres in the horizontal dipole mode) while the vertical dipole mode penetrates roughly twice as far as the horizontal (30 versus 15 metres with 20 metre spacing). However, the vertical dipole mode is much more sensitive to interference from metallic sources such as fences and rail lines, rendering its penetration advantage less than useful in many cases.

Again in broad terms, the maps show a pattern of (what can be assumed to be) normal conductivity (light green to yellow, 8-14 mS/m) with some areas of elevated conductivity (yellow to orange, 14-26 mS/m) and some highly disturbed areas of red highs (>26mS/m) and green to dark green lows(<8mS/m). The disturbed areas are found paralleling the Benzol tank enclosure in the "boundary" area on the SW corner of the COS (hectares E3 and E4), along Coke Ovens Brook (hectares I10 -J13)in one configuration only, Figure 4.6) and in a line along the centre of the Marsh Dump area. Interference from surficial metal also limited the collection of data in some critical areas, e.g. hectares J12- K14. Elevated conductivity levels not obviously associated with the disturbed zones are found near the COS border in the Mullins Bank area, and surrounding the disturbed zones in the boundary area. Significantly, there are no obvious zones of elevated conductivity emanating from the Municipal Landfill boundary. The irregular data (disturbed areas) along the southwest COS boundary are probably associated with the chain link fence and piping associated with the former storage tanks in this area. The broader zones of elevated conductivity values may be halos surrounding the disturbed zones, or they may in fact represent ground contamination moving off site. It is unfortunately impossible to authoritatively separate the two possible causes with the current data, but the possibility of anomalous ground conductivity values in this area should be investigated. The highly irregular data along the centre of the Marsh Dump appears to owe its origins to metal debris, probably in the form of surface or barely buried steel rails. It is more pronounced on the shallow 10H mode (Figure 4.5), and on the laterally sensitive 20V map (Figure 4.7). The high conductivity levels along Coke Ovens Brook on the 20H map (Figure 4.6) possibly reflect the influence of surface

metal on the far side of the brook (lateral as well as vertical detection increases with coil separation). It is likely that such influence on one or two readings has been exaggerated by the edge contouring. Given the limited area available to collect data, we prefer to defer comment on this feature of the 20H map further measurements are made.
The conductivity values in the Mullins Bank area, on the other hand, are relatively low and uniform. Without more conductivity data from the undisturbed geology of this site it is problematic to define "normal"; however, the few well logs we have suggest that conductivity of the overburden is less than 10 mS/m and bedrock less than 2 mS/m. Normal "fill" conductivity values, at least as taken from the dark green contours on the EM-31 conductivity maps, are of the order 15-25 mS/m. Against that background, the Mullins Bank area could be termed slightly anomalous (if there is indeed no remaining fill from the pre-coal-storage era) but certainly not outside the range of what could be expected for natural materials.
That said, there are some patterns within the conductivity distribution beneath Mullins Bank that may be important. On the 10H map (Figure 4.5) there is a suggestion of higher conductivity zones near the COS in the hectares E6 and D8. On the 20H and V (Figures 4.6 to 4.8) maps there is a clear trend within Mullins Bank of increasing conductivity towards the west. Combined with the elevated conductivity values southwest of the disturbed zones in the "boundary " area, these zones may be created by a conductivity plume moving off the COS site to the southwest.

4.3 The geophysical well logs

Natural gamma and electrical conductivity (induction) logs are shown in Figures 4.9a to 4.9f. Their locations are indicated on Figure 3.1. Gamma logs were run with a time constant of 2 seconds and a logging speed not exceeding 1 m/minute. The measured response is plotted at the depth of the sensor. Conductivity logs are run at a logging speed of about 2 m/minute and their response plotted at the centre of the receiver and transmitter coils.

4.3.1 Geophysical logs on the Municipal Landfill boundary

The first four logs (Figures 4-9a to 4-9d) were obtained along the western boundary of the Municipal Landfill in boreholes described by Baechler (1998) and can be compared with the available hydrogeological data from these holes. (The geophysical logs were run in the deepest ("D") of the suite of 4 holes instrumented for sampling at each site.

The complete designation of the logged hole (e.g. JAG-GW-3D) has been abbreviated here (e.g. GW-3) to define the location.) In these holes, bedrock is encountered at depths of 3 to 5 metres and is described as a sandstone with coal and mudstone stringers. Bedrock is described as containing highly fractured zones. Bedrock termed "massive" (non-fractured) is encountered at 16 to 18 metres in boreholes GW-4 and GW-5 (Figures 4-9c and 4-9d respectively).

Examining Figures 4-9c and 4-9d where the geophysical and geological logs can be compared to almost 20 metres, the following points are noted.

1. The gamma log, which normally serves as the "geology" log (independent of groundwater quality) is noisy and not simply related to the core description in these logs. While there is some correspondence between mudstones and gamma highs, our overall impression is that this log is substantially influenced by the borehole grout and is not a reliable indicator of geology in this case.
2. The electrical conductivity logs deviate upwards from a base value in the range of 2 to 5 mS/m. This range can reasonably be considered a "normal" conductivity for the sandstone. Upward excursions (hereafter termed anomalies) from this value could be caused by fracturing (more water content) and/or higher groundwater TDS values within the fractures or the porous matrix.
3. The conductivity anomalies are more elevated at GW-5 than at GW-4, consistent with Baechler's (1998, Figure 7-6) cross-section which shows a TDS plume centred on GW-5. The geophysical logs, however, provide a much more detailed structure of the conductivity anomalies than Baechler's two sampling points at each location can. In the geophysical picture, high conductivity values are found preferentially in distinct layers rather than uniformly (single porous media plume-like) throughout the section.
4. Conductivity levels are seen to be broadly elevated throughout the lower 1-1.5 metres of the overburden and in the upper 5 metres of the bedrock at these two holes. There is a pronounced peak in the conductivity centred on a depth of 7.5 metres in GW-5 (and perhaps a related but smaller peak at 6.5 metres in GW-4). This peak appears to coincide with a fracture zone at GW-5. There is a lower conductivity peak centred on 14 metres depth at GW-5, and 15.5 m at GW-4. At GW-4 this peak coincides with a fractured mudstone described in the core log, and a pronounced high on the gamma log. At GW-5 there is no gamma peak and the core

log indicates "clay infilling on fractures" – but not mudstone - at this general depth.

5. We note that the screen at GW-5 has been set below the conductivity peak at 15.5m depth and may not have sampled the maximum contamination present in this section.
6. The short geophysical (and core) logs at GW-2 and GW-3 do not add much to the picture in the landfill boundary area. From a comparison with GW-2, 4 and 5 the highly variable conductivity log at GW-3 appears to indicate 4 metres of heterogeneous fill.

4.3.2 Geophysical logs within the COS

The remaining two logs (BH-11 and BH-13, Figures 4-9e and 4-9f) are measured at boreholes within the Coke Ovens Site. We were not able to locate core descriptions for these boreholes.(We believe BH-11 to be the BH88-11 and BH-13 to be the BH88-13 referred to in the Phase I report. Although, the locations of these holes as measured with our GPS are approximately 60 and 100 metres from where these are shown in the Phase I report, these are the closest wells indicated and are approximately the same maximum depths as the geophysical logs record.) Both boreholes fall within the low areas of the EM-31 conductivity response.

Electrical conductivity logs at BH-11 and BH-13 show a very highly variable response through the upper 4-6 metres. We can reasonably assume this to be typical of the conductivity distribution of the fill covering the COS site, and it suggests that the EM-31 response is due to "stringers" of slag or other metallic debris within very heterogeneous fill/overburden. Bedrock is found from seismic refraction (in the Test Phase) at about 7 metres beneath BH-11, and has conductivity levels of about 5 mS/m, comparable to what was observed at GW-4 and GW-5. At BH-13, where bedrock depth is not known, there is a pronounced high conductivity and gamma zone centred on 10.5 metres. There are several possible interpretations. The zone may be a clay layer at the base of the overburden, or it could be a contaminated fracture zone within the uppermost bedrock which has become infilled with clay or grout.

5 INTERPRETATION

In Section 4 the data were described in very broad terms preliminary to the more detailed interpretations given here. The EM-31 data are the most complex and their interpretation occupies most of the section.

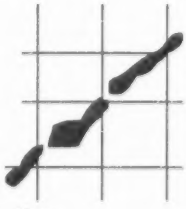
5.1 EM-31 anomalies: how they are described

The plotted maps of EM-31 data have been analyzed in terms of anomalous areas (AAs), regions or features that stand out from their surroundings on one or all of the maps in Figures 4.1 through 4.4. Figure 4.1a and b contain the conductivity responses, and Figure 4.2a and b the in-phase responses.

The terms "in-phase" and "conductivity" are technical terms that are widely used but – as described in Appendix - not self-explanatory. The "conductivity" response, more correctly termed the quadrature response, is used to detect relatively low conductivity features such as contaminant plumes and anomalous ground (fill, previous excavations, etc). The in-phase mode responds best to extremely high conductivity materials, specifically metals. This mode might better be called the "inductance" mode (high conductivity objects develop an EM response that reflects their ability (known as self-inductance) to repel magnetic fields.) Nomenclature aside, the important thing to bear in mind is that the "in-phase" mode is basically a metal detector and the "conductivity" mode an anomalous ground detector. Both modes will respond to most AAs but it is the relative sizes of those responses which determines their category.

The AAs are entered into a database and sorted into four categories, as explained below. The tables in Appendix C are extracted from that database and list the characteristics of the anomalies, their location, our overall confidence in their interpretation (High, Medium, or Low), and comments regarding origin where applicable.

5.1.1 Category L, Linear Features



Because many of the subsurface objects we hope to detect have a linear nature (pipes, ditches, tunnels, etc) any AA that has this characteristic is placed in this category. When a linear is superimposed on a stronger anomaly (such as a broad zone) it may show up as a subtle linear offset in the values of the stronger anomaly. Linears can also be edge anomalies marking, for example, the edge of a building foundation; this subset of the linears has been called "rectilinear" and

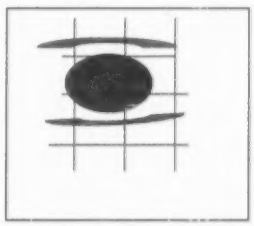
defined further below. Linear anomalies may be positive or negative, and will often have side-lobes of the opposite polarity to the peak. Often a linear will be discontinuous; that is, several individual segments might be detecting a once-continuous subsurface feature that is now interrupted (breakage, corrosion, etc). In that case the possible links between these anomalies are noted. Linears are characterized by their azimuth, relative strength and polarity on the four maps, their overall strength, their locations and their links to other anomalies and known infrastructure, our confidence in their existence and comments by both the field crew and the former site personnel. Anomaly strength and confidence are subjective characterizations determined by the interpreters. Each is broken into three categories, Strong, Moderate and Subtle for strength and High, Medium and Low for confidence. An anomaly may be of moderate or even subtle strength and still enjoy the high confidence of the interpreter. The linear anomalies identified are shown in interpretational Figure 5.1 and coded according to their confidence level. The High and Medium confidence linear anomalies are tabulated in Table C1.

5.1.2 Category R, Rectilinears.

Rectilinear anomalies are a subset of the group of anomalies which have been designated as "linear". These are high confidence linear anomalies which are often rectangular in nature and in many cases form a "regularly" shaped limit to an anomalous zone. Based on their shape they are suspected to result from structures, primarily building foundations, re-enforced concrete slabs, etc.. In some cases these may result from pipes or trenches that have limited the lateral migration of conductive porewater and thereby created a regularly shaped edge to a zonal anomaly.

5.1.3 Category M, Metal

The anomalies associated with "small", isolated buried pieces of metal are typically negative on both the in-phase and conductivity modes if the EM-31 transmitter and receiver straddle the target. Larger accumulations of metal (such that the 3.7 m long EM-31 cannot straddle it) and smaller targets that fall immediately beneath one of the TX or RX coils may exhibit positive responses on both phases. These anomalies are listed in Appendix C

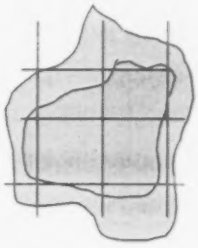


Anomaly Base. These information are also listed in Appendix, giving their number (e.g.M3), location, relative size (small medium and large) and the number of metal targets that might be included (usually 1). The metal anomalies are also plotted on Figure 5.1.

While some anomalies in the linear and metal categories are obvious even to the untrained eye (for example, the feature running north from F5 to H5 best seen on Figure 4.2b) others are more subtle. The low confidence anomalies are sometimes very subtle and can prove to be difficult to ground truth. Experience has shown, however, that these subtle anomalies often turn out to have a subsurface cause, perhaps a very deep pipe or a foundation remnant which has only a low conductivity contrast with its surroundings, a trench from a former excavation,etc..

Our philosophy in this case is that it is better to over-interpret than under-interpret the data. It is better that a crew excavating the site be prepared for what they might find, even if that target never materializes to the depth that they dig. Our approach has been to pick every feature that looks as though it might originate in the subsurface, using the three categories described above. We have further labeled each pick with some measure of size, strength or confidence that allows us to rank their importance. Nevertheless, it must be emphasized again that there will be a certain percentage of the subtle anomalies interpreted for which the cause will not be readily identified during excavation.

5.1.4 Categories Z (Zones)



These are broad regions of higher conductivity response than their surroundings. These zones are typically areas of ground contamination, or of disseminated metal objects whose individual anomalies run together.

The Zone anomalies are defined in this case in a fairly simple way. The NS and EW EM-31 conductivity maps have been smoothed and averaged. The resulting data have been contoured in 4 levels, 50, 100, 200 and 300 mS/m, and plotted on interpretation Figure 5.2. Colour has been applied to those areas lying above the 300 contour (purple), between the 200 and 300 mS/m contours(red), between the 100 and 200 mS/m contours (dark orange) and between the 50 and 100 mS/m contours (light orange).

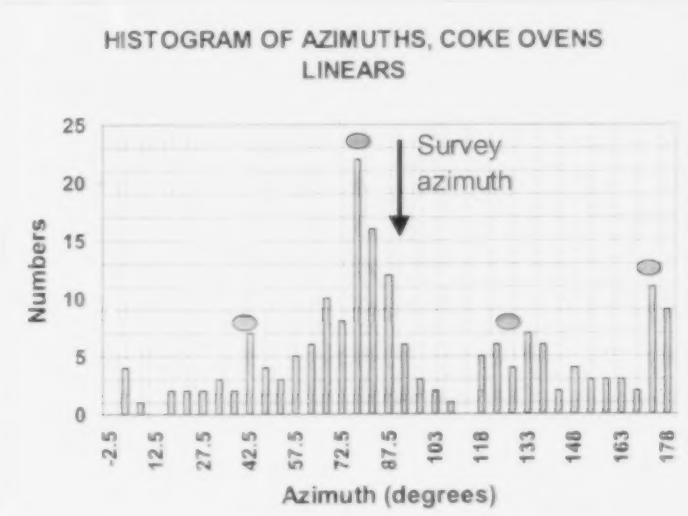
Conductivitiy values in the range 0-50 mS/m have not been coloured. This does not imply that these are all normal; the base level of EM-31 conductivity for the site is about 20mS/m. The zones are intended to highlight the individual pockets and broad areas where possible ground contamination in the form of elevated electrical conductivity exists.

5.2 Details of the EM-31 anomalies

5.2.1 Linears

The linears identified from the EM-31 data are shown on Figures 5.1. The linears (including rectilinears) are tabulated in Table I of Appendix C. with relevant comments by ourselves and by former site manager Eric Parsons Sr.

The azimuths of all the linears picked are not randomly distributed. The largest grouping (approximately 33% of the total) is found between azimuths 75° and 100° with its peak at about 80°. The second largest grouping (~11%) lies between 165° and 180° with its peak near 170°. Smaller peaks are found lying midway between these two orthogonal groupings, near 40° and 130°. These statistics suggest some order to the sources of the anomalies. There is reason for concern that the azimuthal groupings lie close to the directions (NS and EW) along which the survey lines were run, and could perhaps be artifacts of the collection and processing. However, the consistent offset of 10° of the groupings from these line directions suggests otherwise. Instead a more likely pattern correlation is with the layout of the plant. The Phase I report (CBCL/CRA, 1998, p. 34) notes that:



"The Coke Ovens plant was laid out in a nominal south-east to north-west alignment with material and process flow in a nominal north-east to south-west direction."

An examination of the site maps and air photos suggests that the predominant structures are in fact rotated only slightly from east-west and north-south, and by about the 10° indicated by the linear groupings.

The figures and database have been specifically setup to provide ease of identification and further study. In Section 6 we suggest how these data, the figures and database can be used to undertake other activities.

5.2.2 Metals

We have examined the four maps for these anomalies, and have identified 200 possible occurrences which are plotted on Figure 5.1. In each case there may exist one or more objects at a given location. Note that in the broad areas of elevated in-phase and conductivity values some metal anomalies may go undetected.

5.2.3 Zones

The conductivity zone map is shown in Figure 5.2. As described above, the conductivity range has been divided into five colours (including white). The overall impression is of discrete, blocky, extremely high conductivity zones surrounded by halos of lesser conductivity. That is, there are comparatively few discrete orange or green zones, and they are small where they occur. We discuss these zones under two headings.

5.2.3.1 The origin of the very high conductivity zones (red, purple on Figure 5.2))

The extent of very high conductivity zones encountered on the site was considerably larger than expected based on the surface materials observed. Coal, coal dust, tar and the metallically-depleted slag we observed on the surface are not usually thought of as conductive. Their leaching by-products, some dissolved inorganic species, acids and perhaps organic acids might be considerably more conductive but would not be expected to produce the extreme levels of conductivity recorded locally.

The blocky morphology of these zones, their high electrical conductivity levels bounded in many case by linear boundaries, suggests to us that their source is conductive slag within fill that has been deposited within defined areas. The defining boundaries may have been fences, walls or roadways in use at the time of deposition. Surrounding these bounded zones are halos of lower but still anomalous conductivity , possibly representing plumes originating from the slag material or from other chemical contaminants within the groundwater.

The in-phase component, primarily a metal detector, is probably the best indicator of slag content while the conductivity response may be the best definer of the plumes. This interpretation is buttressed by the observations of Eric Parsons Sr., former manager of the site.

"During construction of # 5 and #6 Battery, slag was used as a fill material. In all probability, this was non-processed "in kind" material which could have been high in metallic content. All "in plant" roads were made from slag based material and in the Coke Ovens these roads would have a considerable amount of coal, coke and coke braise ground into the road base, ie. giving high electrical conductivity readings throughout the site.

I definitely feel there was a lot more metallic slag used as fill during construction from the turn of the century to the 50's era, than would be used today; couple this with the ground being saturated with coal and coke fines from the late 1890's to 1988 and add to that the great amount of chemicals in the soil, ie. tar, flushing liquor, sulfates, acids, oil based products, plus steel and cast iron material that was buried as part of the overall construction program and you certainly have soil with a high electrical conductivity. If one examines each process area from the point of view of demolition of structures and leveling off areas to grade with high metallic slag fill; plus the composition and complexity of the underground systems, two key items come to the foreground, those being high electrical conductivity soil bearing material along with "blocky" red zone patterns representing the changing process over time, covering a very large area of property. These ancient boundaries (approx. 92 years)represent building and equipment associated with the process during this time frame, i.e. the "blockiness" and very linear boundaries associated with this site."

The suggestion is that slag from earlier years was more metallic on average than the samples we observed on the surface, and that this metallic slag is the predominant cause of the extremely high conductivity values. Clearly it is important to measure the electrical conductivity of these materials if and when they are unearthed.

Of particular interest is the high conductivity zone coincident with the present tar lagoon in area H1. Tar is not generally conductive, and while some of its contained by-products might be somewhat conductive, it was difficult to reconcile the extremely high EM-31 readings recorded. Again quoting Eric Parsons Sr. ...

"During the period when we were storing coke because of overproduction on Batteries

#5 and 6, additional space was required for the excess. It was early winter and cold and it was decided that we would use the Domtar Pond area for coke storage. A slag base was deposited over the tar surface and we proceeded to store approximately 5000 tons of crushed metallurgical coke in this area. The coke was removed before the spring thaw."

The implication is that the slag near the base of this pond is the source of high conductivity values observed.

5.2.3.2 The origins of moderate conductivity zones (light and dark orange, Figure 5.2)

Readings below 100 mS/m, while still high, are in the range sometimes observed in areas of contaminated groundwater near landfills and waste lagoons. We do not have access, at time of writing, to extensive data on measured groundwater conductivity levels at the site. Data we have acquired from a report by Nolan Davis Associates Limited and Jacques Whitford Associates in 1990, show groundwater TDS levels in the upper 2 metres to be typically three times background. The most contaminated reading was from the Mullins Bank area, about 10 times background at a depth of 1.2 m.

The light and dark orange zones of Figure 5.2 could therefore be low density (for example very thin layers) slag deposits, other forms of conductive fill, high TDS groundwater or a combination of the above. Without sampling (see Recommendations, section 7) it is unwise to speculate further. We note, however, that if the origin is in fact conductive groundwater it will also probably underlie the slag and be undetectable until such time as the slag is removed.

5.3 EM-34 interpretation

5.3.1 Modeling

Software for performing one dimensional direct modeling of the EM-34 response is readily available; however, without a better knowledge than we have of background conductivity levels it is not particularly useful. Predicted EM-34 responses based on one dimensional models of the conductivity logs at GW-4 and GW-5 were roughly 50% of what is observed in the Marsh Dump region. Unfortunately, cultural interference (pipes, rail lines) precluded the collection of EM-34 data immediately beside these monitoring wells for a direct comparison. It would be unwise to assume that the materials underlying the Marsh Dump survey are similar to those encountered at the wells. Reports indicate that up to 20 metres of fill can exist there, while only a few metres of fill

were observed in wells GW-1 to GW5.

5.3.2 Implications for ground contamination

If the subsurface to depths of tens of metres in the Mullins Bank or Marsh Dump is in fact heavily contaminated by conductive (inorganic) species, that contamination is probably confined to discrete fractures or even lithological zones. The EM-34 readings of bulk ground conductivity are simply not high enough to sustain a scenario of pervasive, uniformly distributed high conductivity porewater throughout the host materials to these depths. The readings do not rule out some near-surface (upper 1-2 metres) anomalous high conductivity materials, but nothing as high as is observed on the COS proper. More probable, we believe, is that these the geological sections sampled by these measurements are not, on average, highly contaminated by conductive species.

The patterns observed in the EM-34 contouring in the Mullins Bank and SW boundary areas do depict patterns consistent with low level conductivity plumes moving out of the COS proper. Comparing the variation of conductivity values with increasing EM-34 penetration show the highest values in this area are within the 10H readings (7½ metre penetration) and the conductivity generally decreasing with increasing instrument penetration. This implies that the conductive zones are relatively shallow.

The EM-34 data near the Municipal Landfill boundary, perhaps surprisingly, do not suggest a plume moving away from that feature in the area surveyed. Where the data have not been influenced by cultural features, the conductivity readings in all instrument modes are similar, indicating a relatively uniform distribution of conductivity with depth. The implications of this are discussed further in the next section, but we note here that this is consistent with the well logging and sampling results at boreholes along the landfill boundary.

In the area south and west of the Benzol tanks (E3,E4,D5 and C5) the conductivity values increase with EM-34 sampling depth. While there is little doubt that some cultural interference occurs in this data, there is still a strong indication that the subsurface has elevated conductivity values. These elevated conductivity levels both increase in value and become broader area as the penetration of the EM-34 increases.

5.4 Geophysical well logs

As noted in section 4.3.1, we are concerned that high readings on the gamma logs are mapping concentrations of grout rather than borehole lithology. The key features of the

individual logs were described in that section. The apparent conductivity logs at GW-4 and GW-5 suggest that conductive contamination leaving the landfill is confined to discrete fracture zones or lithological zones. On this basis a conceptual cross-section of the contaminant plume is presented as Figure 5.3. This refines the section which was originally described by Baechler based on the available (very limited) number of sample points. The geophysical data imply a contaminant migration immediately east of the Municipal Landfill along near-horizontal fractures and fracture zones rather than as a large bulbous plume. This refined section is consistent with the water quality analysis presented in the earlier report. This type of contaminant transport is difficult to characterize with discrete sampling points.

This interpretation is also consistent with the EM-34 results. Conductive contamination which is confined to relatively thin horizontal zones does not influence the bulk conductivity of the subsurface as measured with the EM-34 nearly as much as it would were it moving through a broader cross-section of the matrix. The EM-34's sensitivity to the thin layer decreases drastically when the zone is deeper and further from the instrument. Depending on its' distribution, the fracture zone's variations in thickness etc., the contaminant may have only a subtle impact on the EM-34 measurements and be difficult to recognize, particularly in the presence of cultural interference.

6 USING THIS INFORMATION

There are many possible uses of the data presented in this report. We foresee these uses falling into two general categories.

6.1 The overall view.

The maps provide a broad and very visual overview of the subsurface of the COS and its surroundings. This overview can be critical in grouping and dividing the complex site into smaller areas which are of a manageable size for further investigation. It has been found in other projects of this type that the visualization is readily appreciated by those unfamiliar with the complex technical aspects of the site.

6.2 Investigating small areas.

Ultimately the clean-up process will come down to sampling or excavating small areas. The details of the actual cleanup will depend on the consultant of the day. The data and interpretation maps can be reproduced at any scale and for any portion of the site. The data base can be sub-sampled on a hectare by hectare basis. By way of demonstration we have reproduced the working maps and database information for hectare E6, in Figures 6.1and Tables 6.1 and 6.2 respectively.

The nodes of the grid have been marked in the field and should be locatable for several months at least. After these are located, the position of individual anomalies within the grid can be accurately located with a tape measure. Alternatively a GPS system can be used to locate these features. Note that the grid co-ordinates are in the specified local system whereas most GPS instruments will be operating in a UTM system. A translation and a rotation are required to link these. In areas where zonal anomalies overlap discrete features, there may be a need to re-survey the area geophysically once sources of surface interference have been removed.

6.3 Extracting more information from these geophysical data.

Our interpretation has been fairly qualitative. We have not made extensive use of the physics that in theory links our measurements quantitatively to the physical properties and structure of the subsurface. For example, we have not attempted to extract pore fluid resistivity or target depth from the terrain conductivity data. Nor have we attempted

Archie's Law analysis of the conductivity logs, or any detailed pattern recognition of their (and the gamma log) behavior.

Experience warns us not to go into this level of detail at this stage! The scan data, for example, are measurements of three dimensional electromagnetic fields made on a single two-dimensional (the ground) surface. No interpretation for the exact sources of these fields can be unique with such a narrow perspective. More ground truthing (boreholes, excavations, understanding the "slag" mystery, and etc.) may constrain the geophysical data to the point that more detailed interpretations could be attempted, but we prefer to leave that for later.

TABLE 6.1 Catalogue of Major Coke Ovens EM-31 Linear Anomalies: Hectare E6

Anomaly	Location	Azim. (deg)	Hyd-Eng Comments	Site Personnel Comments
Confidence Level:			**HIGH**	
L408	E5 E6	80	Appears to be the southern boundary of the Batteries 5 and 6. Note there is a real discrepancy between the positions of the batteries 5 and 6 on General Plan map and the Phase I map. The former puts the battery 45 to 61 metres north of the by-products building. Which is right??	Appears to be 500 mm FW lines running full length of the batteries. It appears the GP map is correct. I make it approx. 41 to 67 metres north of the BP building centre line to centre line
L409	E5 E6	80	Possibly rail lines south of the battery.	Or possibly 750 mm surplus gas line.
L413	E5 E6	82	Possibly rail lines south of the battery	150 mm surplus supply line to tar holding tanks.
L431	E6	90	Along road edge. Metallic	Appears to be 300 mm outlet sewer dumping directly into 1800 m storm sewer.
L434	E6	83	Possibly rail lines south of the battery	600 mm fuel gas main to #5 battery.
L435	E6 E7	77	Possibly rail lines south of the battery	600 mm outlet fuel gas main to #6 battery.
R436	E6 E5	74	N/C	N/C
L437	E6	79	Metallic. Subparrallel to Railroad. Side track?	Possibly 750 mm gas line going to bleeder stack.
L438	E6	25	Short linear, metallic.Origin??	Possibly 150 mm tar loading line from the tar pumps.
Confidence Level:			**MEDIUM**	
L412	E5 E6	94	Metallic, connected with road bed?	200 mm sprinkler system.
L432	E6 E7	76	Another road trend?	Coke ovens main (200mm sprinkler same area)
L433	E6	108	Appears to extend from BP bldg to conveyor area.	750 mm gas line from BP Building.

Hyd-Eng Geophysics: Coke Ovens Project **N/C = No comment**

TABLE 6.2. Catalogue of Coke Ovens EM-31 Metal Anomalies: Hectare E6

Anomaly	Number Objects	
M178	1	Anomaly Size: MEDIUM
M179	1	
M180	1	
M181	2	*Anomaly Size:* SMALL
M182	1	
M183	1	
M184	1	
M185	1	
M186	1	
M187	1	

7 CONCLUSIONS AND RECOMMENDATIONS

The results of the survey are summarized briefly below. We also recommend additional geophysical work that could be undertaken at the COS site. We do not presume to provide recommendations regarding other forms of testing, site remediation or hydrogeology, leaving this for others with a more detailed understanding of those disciplines.

7.1 The Coke Ovens Site: a summary

The Coke Ovens Site is a highly complex, electrically conductive area, the result of a large subsurface infrastructure, ground water contamination, and – we propose – a very considerable volume of a highly metallic slag. We have mapped the lateral distribution of this conductive structure in detail, identifying linear, isolated metal and zonal anomalies that originate in the upper 3 to 5 metres and that will have to be addressed in any remedial operations. This extensive veneer of highly conductive materials precludes our penetrating farther into the subsurface in portions of the COS proper. Geophysical sampling of the conductive nature of the COS beneath 5 metres depth will have to await clean up of the near-surface sources.

The areas bordering the site are for the most part comparatively normal in terms of electrical conductance. Apart from some highly disturbed responses near surface metal (fences, tanks, rail lines) the values recorded by the EM-34 are low. There is no evidence in the EM-34 data of a pervasive conductivity plume from the Municipal landfill in the area surveyed, although we cannot rule out continuous concentrations along narrow zones. There is a suggestion of weak conductive plumes emanating from the COS to the south and southwest.

Geophysical logging of 4 holes in the Marsh Dump area suggest strongly that contamination by the Municipal Landfill is confined to discrete fractured zones in the bedrock, explaining the lack of a large conductivity response from the geologic section as a whole near the landfill boundary.

7.2 Refining the detailed interpretation of linear and metallic anomalies

The geophysical survey provides a representation of the infrastructure of the site that is considerably more complex than the historical review of the Phase I report would

suggest. This is partially because the COS is the entire focus of this investigation, while only one region within the entire Muggah Creek watershed with which the Phase I report was concerned.

We have described the most probable causes for the majority of the strong and moderate linear anomalies, and demonstrated how this information can be used. A review of the likely origins of all the linear and metal anomalies is beyond the scope of this study, but should be considered.

7.3 Groundtruthing the COS geophysics by selected sampling

The results of the geophysical investigation are an interpretation that will require direct groundtruthing. That interpretation, summarized above, is based on a large base of observed data but it is nonetheless subject to a number of assumptions. Chief amongst these is that the very highly conductive areas on the EM-31 maps result from metallic slag. Sampling of these areas, and of the conductive halos surrounding them that we have suggested represent groundwater contamination, is required to confirm this interpretation.

7.4 Mapping bedrock.

The topography of the bedrock beneath the site is important to an understanding of any contaminant flow that might be occurring. We demonstrated in the Test Phase (see Appendix B) that bedrock could be mapped in one area relatively free of infrastructure. (At a second we were thwarted by frozen ground). This limited experience in performing refraction surveys at the site has shown us that bedrock is very probably a good seismic target. In areas with large accumulations of near-surface heterogeneities (natural and anthropgenic) more difficulty in obtaining clean signals from the basement will almost certainly be encountered. We cannot predict with any confidence the severity of any problems that could arise in these areas, however, and would advise further refraction testing of the site before undertaking a major mapping program. Nevertheless, we now know (from the EM-31 maps) where problems might be encountered and, based on past experience, we would expect that 80 to 90 percent of the site could be mapped. While the seismic surveys can be undertaken independently of other activities on the site, it is true that a seismic refraction interpretation is greatly assisted by ties to a few well distributed boreholes that penetrate the bedrock. For that reason it would make

sense to coordinate the seismic program with any drilling program that is undertaken.

7.5 Geophysical well logging.

We emphasize the usefulness of induction (conductivity) logs for determining and monitoring the vertical distribution of groundwater conductivity in the subsurface of and around the Coke Ovens Site. The improvement in our understanding of the situation at boreholes GW4 and GW5 relative to the simplified picture based on one or two screened intervals is well worth the effort.

We recommend that a conductivity survey of the existing boreholes be undertaken. We also highly recommend that any new boreholes be geophysically logged prior to monitoring well installation and subsequently logged to augment the groundwater monitoring program. Repeated geophysical logging is an integral part of the groundwater monitoring program at a number of sites in Canada and the United States. Ideally a network of 10 to 30 boreholes would be established across the site to provide a better map of the present conductive structure and to allow future monitoring through sampling and logging as Phase II efforts progress. Other logging tools are also available which can be used to determine either fracture orientation or water movement within fractures.

8 REFERENCES

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9 LIMITATIONS OF REPORT

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